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ACCELERATOR DEPARTMENT
Annual Progress Report
1 January - 31 December 1984

Abstract. A description is given of work in the fields of radiation chemistry and reaction kinetics, physical dosimetry, radiation physics and technological application of radiation, radiation bacteriology research and irradiation technology, as well as of the operation of various irradiation facilities.

Inis-descriptors ACCELERATOR FACILITIES; BACTERIA; DOSEMETERS; DOSIMETRY; IRRADIATION DEVICES; RADIATION CHEMISTRY; REACTION KINETICS; RESEARCH PROGRAMS; RISOE NATIONAL LABORATORY.

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PREFACE

The objectives of the Accelerator Department are to conduct research in processes based on ionizing radiation and to contribute to its industrial utilization.

Three electron accelerators of 10-, 2-, and 0.4-MeV, cobalt-60 facilities of 3- and 10-kCi, and a Multigas Excimer Laser EMG 102E equipped with various experimental facilities, are at our disposal.

A major research effort is directed towards a better understanding of basic chemical processes and in particular the reaction kinetics. The applied techniques include pulse- and steady-state radiolysis, laser flash-photolysis, stop-flow experiments, and computer simulations.

A proper measurement of the absorbed dose is a prerequisite for application of radiation in research and industry. Research is conducted into the response mechanisms of dosimeters and in the development and calibration techniques of dosimeters for gamma and electron irradiations.

The mechanisms leading to destruction of microorganisms have been subjects of the research program, as radiation sterilization is one of the major industrial applications of radiation. This programme was closed down per 31 December 1984, as the bacteriological group has been transferred to the Agricultural Department to conduct research in biotechnology.

Commercial test irradiations may be carried out at all our radiation facilities, but only the 10-MeV electron accelerator is equipped for full-scale industrial purposes. Consultive and advisory assistance is rendered in connection with commercial irradiation, including, e.g. calibration of a customer's dosimeter systems.

One of the staff members (J.W. Hansen) defended his thesis (lic.scient) at the University of Copenhagen.

This report describes the principal activities in these fields for the period 1 January - 31 December 1984.

The contributions marked * are abstracts of published papers.

1. RADIATION CHEMISTRY AND REACTION KINETICS

1.1 Products from the decay of the carbonate radical ion

(K. Sehested, E. Bjergbakke, J. Holcman, and E.J. Hart (Port Angeles, WA, USA))

The bimolecular reaction of the CO_3^- radical ion was determined from pH 8 to pH 13. There is no evidence for a pK of this radical in this pH range, neither from the spectrum and extinction coefficient nor from the rate constant. The CO_3^- radical reacts with O_2^-, H_2O_2, and HO_2^- with the rates 3.15×10^8, 4.5×10^5 and 3.0×10^7 $dm^3mol^{-1}s^{-1}$, respectively. The postulated CO_5^- (reaction between CO_3^- and O_2^-) could not be confirmed. The product of the bimolecular reaction was studied by applying 1 μs, 4.5 krd electron pulses to a carbonate solution in intervals of 2 and 10 seconds. The product was measured as hydrogen peroxide in acid solution by oxidation of ferrous ions. Both the spectrum of the product and the rate constant for the ferrous ion oxidation ($k = 50$ $dm^3mol^{-1}s^{-1}$) agree with the assumption that the product, when acidified, is hydrogen peroxide. The yield decreases with increasing pH. At pH 8.5 the yields are almost proportional to the number of pulses, whereas at pH 12 further pulses do not add to the yield of the first pulse. At pHs > 12 there is a distinct effect of the time lapse between the pulses, which suggests that the product is not initially formed as hydrogen peroxide, but rather as a peroxycarbonate. A build-up of the hydrogen peroxide spectrum with a rate depending on pH and computer simulation of the mechanism also suggests a formation of peroxycarbonate, which hydrolyses to hydrogen peroxide. pK of the peroxycarbonate (in analogy to carbonate) can be demonstrated

$$CO_4^=(\text{or } C_2O_6^=) \rightleftarrows HCO_4^- \rightleftarrows H_2CO_4 \rightarrow H_2O_2 + H_2O + CO_2$$

The values are around 11.5 and 8.

1.2 γ-ray initiated chain decomposition of aqueous ozone solutions*

(E.J. Hart, (Argonne National Laboratory, Argonne, IL 60439, USA), K. Sehested, E. Bjergbakke, and J. Holcman)

The free radical-initiated chain decomposition of aqueous O_3-O_2 solutions was studied as a function of dose rate and O_3 concentration in the pH range, 2.0-7.0. At dose rates of 10 rds^{-1} or less extensive chain decomposition of

O_3 occurs. Under these conditions impurities arising from the water, glassware, O_3, acids and buffers suppress decomposition. In the absence of impurities, the decomposition rate is 1st order in O_3 concentration in the range from 50-200 μM and achieves chain lengths of 200 to 300. A typical decomposition curve is autocatalytic, with a low initial rate, a rapid middle rate and, as the O_3 concentration approaches zero, a slow final rate. These complex decay curves have been analyzed by measuring the decomposition rates at 50, 30, and 15% of the initial O_3 concentration. The yields per 100 μm O_3 increase with increasing pH to a broad maximum at pH 4.0 and thereafter decline slightly. The propagation reactions in this chain mechanism are: $O_3 + O_2^- \rightarrow O_3^- + O_2$; $O_3^- + H^+ = O_2 + OH$; $OH + O_3 \rightarrow HO_2 + O_2$; $HO_2 = H^+ + O_2^-$. The termination reactions are: $HO_2 + OH \rightarrow H_2O + O_2$ (dominant at low pH; $OH + OH \rightarrow H_2O_2$ (dominant at pH > 4); $OH + X \rightarrow XOH$ (dominant with X as an impurity). The decay curves may be simulated by the water radiolysis mechanism including the above reactions. The overall behaviour of the system conforms to an impurity level with kc's in the range of 10-100 s^{-1}. For example, at an impurity level with kc's in the range of 1.0×10^{-6} M and a rate constant of 10^8 $M^{-1}s^{-1}$, kc = 100 s^{-1}.

1.3 Pulse radiolysis of acetate-ozone solutions

(K. Sehested, J. Holcman, E. Bjergbakke, and E.J. Hart (Port Angeles, WA, USA))

Acetate is one of the main products left in water after ozone treatment. It is also known to inhibit ozone decomposition in water. On pulse radiolysis of "oxygen free", N_2O saturated ozone-acetate solutions at pH = 9-10, formation of the O_3^- radical has been observed as a build-up at the 430 nm band. The O_3^- radicals form on the expense of acetate radicals. The band at 350 nm (acetate radical) reveals that formation of O_3^- takes place in two kinetically coupled steps:

I	$O_3 + CH_2COO^- \rightarrow P$	$k_I \sim 2 \times 10^9$ $dm^3mol^{-1}s^{-1}$
II	$P + O_3 \rightarrow O_3^-$	$k_{II} \sim 1 \times 10^9$ $dm^3mol^{-1}s^{-1}$

k_I and k_{II} were found by computer simulation of the traces at 350 and 430 nm. The decrease in absorption observed at the 260 nm band confirms the stoichiometry of two ozone molecules used for every O_3^- formed. At pHs below 7 in buffered solutions the formation of O_3^- radicals is not observed, but a rapid chain decomposition of O_3 is observed at 260 nm. This observation is consis-

tent with the findings at pH = 9-10 and the immediate conversion of O_3^- to OH by H^+ and/or the buffer. At pH = 9-10 oxygen was found to reduce $G(O_3^-)$, and a pronounced inhibition of the O_3 chain decomposition by oxygen is demonstrated below pH 7. The influence of oxygen is explained by the scavenging of acetate radicals to form the relatively unreactive peroxy acetate radical. Further information about the products of the radiolysis in the acetate-ozone system is required before a more detailed mechanism can be offered.

1.4 Decomposition of O_3 in alkaline solutions; stopped flow experiments

(K. Sehested, J. Holcman, E. Bjergbakke, and E.J. Hart (Port Angeles, WA, USA))

Kinetics of O_3 decay in alkaline media was measured using the Aminco-Marrow stopped-flow apparatus of the Medical Biochemistry Department at the University of Aarhus. It was found that the results with carbonate added as a radical scavenger at high concentrations are reproducible and can be modeled by the computer simulation using recently obtained data on the CO_3^- decay. The results with the decay of O_3 in "pure" alkaline solution are less reproducible and an attempt to obtain a consistent computer model for this process failed. This can be explained by sensitivity of the system to the presence of minute concentration of impurities like, e.g. $CO_3^=$. Further stopped-flow experiments with a better control of purity are needed to resolve the mechanism of O_3 decomposition in "pure" alkaline solution.

1.5 Standard Gibbs energy of formation of the hydroxyl radical in aqueous solution. Rate constants for the reaction $ClO_2^- + O_3 \rightleftarrows O_3^- + ClO_2$*

(U.K. Kläning (Institute of Chemistry, University of Aarhus), K. Sehested, and J. Holcman)

The rate constants of the following reactions were determined by pulse radiolysis and stopped-flow experiments: $ClO_2^- + O_3 \rightleftarrows ClO_2 + O_3^-$ ($k_f = (4 \pm 1)\times10^6$ $dm^3mol^{-1}s^{-1}$, $k_r = (1.8 \pm 0.2)\times10^5$ $dm^3mol^{-1}s^{-1}$); $ClO_2 + OH \rightarrow ClO_3^- + H^+$ ($k = (4.0 \pm 0.4)\times10^9$ $dm^3mol^{-1}s^{-1}$); $ClO_2 + O^- \rightarrow ClO_3^-$ ($k = (2.7 \pm 0.4)\times10^9$ $dm^3mol^{-1}s^{-1}$); and $O_3 + ClO_2 \rightarrow ClO_3 + O_2$ ($k = (1.05 \pm 0.10)\times10^3$ $dm^3mol^{-1}s^{-1}$), where k_f is the forward rate and k_r is the reverse rate of reaction. The standard Gibbs energy of formation of OH in aqueous solution, $\Delta_fG^\circ_{aq}(OH)$ and the corresponding standard reduction potential $E^\circ_{aq}(OH/OH^-)$ were determined by means of k_f and k_r, the equilibrium constant of $O_3^- \rightleftarrows O_2 + O^-$, the pK of the

hydroxyl radical, $\Delta_f G^\circ_{ao}$ of O_3, O_2, and OH^- in aqueous solution, and $E^\circ_{ao}(ClO_2/ClO_2^-) = 0.934$ V determined in the present work. $\Delta_f G^\circ_{ao}(OH) = 26.8 \pm 1$ kJ mol^{-1} and $E^\circ_{ao}(OH/OH^-) = 1.91 \pm 0.01$ V are obtained.

1.6 Laser flash photolysis of aqueous solutions of Br^-

(U.K. Kläning (Institute of Chemistry, Aarhus University) and K. Sehested)

Aqueous solutions of Br^- were photo-ionized with 10 ns pulses of laser light of wavelength 193 nm from the E102 Lambda Physik Excimer laser. The rate constant for the formation of Br_2^- was found to be 1.1×10^{10} mol $dm^{-3}s^{-1}$.

1.7 Pulse radiolysis of selenite and selenate. Properties of Se^V

(U.K. Kläning (Institute of Chemistry, Aarhus University) and K. Sehested)

Pulse radiolysis of selenate and selenite solutions in the pH range 0-14 was studied. The reaction of OH with the selenite ion, the acid selenite ion and selenous acid and O^- with the selenite ion produces a Se^V species, which is identical to the species produced by the reaction of e^-_{aq} with the acid selenate ion and the selenate ion. At $0 < pH < 13$, Se^V has a spectrum with a band centered at 430 nm. In strongly alkaline solution the band shifts towards shorter wavelengths with increasing hydroxide concentration. At $pH < 11$ the Se^V species decays in a second-order reaction with a rate constant which is independent of pH. Se^V in selenate solutions at $pH > 12$ decays in a pseudo-first-order reaction with a rate constant which increases with increasing hydroxide concentration. No reaction was observed of H and OH with selenate and acid selenate ions, neither of H with selenous acid, acid selenite nor selenite ions.

The findings suggest the following mechanism:

$$2SeO_3^- + SeO_3^{2-} + (SeO_3 + H_2O \rightarrow SeO_4^{2-} + 2H^+)$$

$$SeO_3^- + OH^- \rightleftarrows HSeO_4^{2-} \rightleftarrows OH/O^- + SeO_3^{2-}$$

$$HSeO_4^{2-} + OH^- \rightleftarrows O^- + SeO_3^{2-} + H_2O.$$

From the equilibrium reactions the standard reduction potential E_0 for the couple SeO_3^-/SeO_3^{2-} can be derived ($E_0 = 1.70$ Volt). This is in accordance with

the oxidation of CO_3^{2-} to CO_3^- by SeO_3^-.

1.8 The hydrated electron and its reactions at high temperatures

(H. Christensen (Studsvik Energiteknik AB, Sweden) and K. Sehested)

The spectrum of the hydrated electron has been determined in the temperature range 5-300°C using strongly alkaline solutions and high hydrogen pressure. At temperatures up to about 150°C the temperature coefficients of E_{max} and $\Delta E_{1/2}$, are -2.8×10^{-3} eV K^{-1} and 2×10^{-4} eV K^{-1}, respectively. E_{max} is the energy at maximum absorption and $\Delta E_{1/2}$ is the half-width of the spectrum. The temperature coefficient of εG is 50 ± 10 $dm^3mol^{-1}cm^{-1}K^{-1}$ in the temperature range 5-300°C. εG at 21°C is 1.18×10^5 $dm^3mol^{-1}cm^{-1}$ in these solutions.

The rate constant of the second-order decay (2k) is $(1.00 \pm 0.05)\times10^{10}$ $dm^3mol^{-1}s^{-1}$ at 20°C, independent of pH. The activation energy of the reaction is 23 ± 1 kJ mol^{-1} (5.4 ± 0.2 kcal mol^{-1}) at temperatures up to 150°C.

The decay at temperatures above 150°C becomes slower with increasing temperatures but still follows second-order kinetics for 2-3 half-lives. At these high temperatures it is impossible to avoid dissolution of silicium dioxide from the synthetic quartz cell. The silicium dioxide dissolves as silicate, SiO_4^{4-} or SiO_3^{2-}, which lower the pH of the starting solution. The final pH of the heated and irradiated solution is measured together with the silicon dissolved, and they correlate well with the pK of the silicate at 9.7 and 12. As long as the final pH is higher than ~ 10, the decay rate is still decreasing with temperature, but if the final pH becomes lower than ~ 9 because of dissolved silicate, the decay rate raises. The decay seems to be independent of the concentration of silicate in experiments, where the starting concentration and thereby final concentration is varied. Also, even at the highest concentrations silicate did not disturb the electron spectrum, half-width or εG to any significant degree at ambient and higher temperatures.

The simplest mechanism capable of describing the kinetic data at various temperatures is the equilibrium

$$e^-_{aq} + e^-_{aq} \rightleftarrows (\text{intermediate}) \rightarrow H_2$$

where the back reaction has a higher activation energy than the forward one. The intermediate species may be designated (e^{2-}_{2aq}), (e^-_{aq},H) or H^-_{aq}, where the

last two species are the first step towards the final product, the hydrogen molecule.

1.9 Activation energy for the reaction $H + OH^- \rightarrow e^-_{aq} + H_2O$ and kinetic determination of the enthalpy and entropy of hydration of the electron in water

(B. Hickel (CEA - CEN/SACLAY, France) and K. Sehested)

Applying high pressures of hydrogen to convert OH radicals to H atoms, the formation of hydrated electron from the reaction $H + OH^- \rightarrow e^-_{aq} + H_2O$ was studied at pH 12 in the temperature range 15-60°C. The Arrhenius plot yields an activation energy of $E = 6.3 \pm 0.6$ Kcal mol^{-1} for this reaction. The activation energy and the standard free energy of the reverse reaction have been determined previously, $E = 4.5 \pm 1$ Kcal mol^{-1} and $\Delta G° = 5.9$ Kcal mol^{-1}, respectively. Thus the standard enthalpy $\Delta H°$ and entropy $\Delta S°$ for the reaction are derived and the thermodynamic properties of hydration of the electron in water can be calculated.

1.10 Radiolysis of aqueous solutions of ammonium bicarbonate over a large dose range*

(Z.D. Draganić, I.G. Draganić, A. Negrón-Mendoza, R. Navarro-Gonzales, M.G. Albaran-Sanchez (Centro de Estudios Nucleares, Universidad Autonoma Nacional de Mexico) and K. Sehested)

O_2-free aqueous solutions of 0.05 mol dm^{-3} ammonium bicarbonate were studied after receiving various doses of ^{60}Co gammas (0.001-170 Mrd) or krd pulses of 10-MeV electrons. Formate, oxalate, formaldehyde and an unidentified polymer (M_W 14000-16000 daltons) were found to be the main radiolytic products. It has been concluded that the reaction $CO_2^- + HCO_3^- \rightleftarrows HCOO^- + CO_3^-$ is responsible for the large initial yield of formate in the γ-radiolysis, $G(HCOO^-) = 2.2$, and that $CO_2^- + CO_3^-$ contributes to other pathways leading to the reformation of bicarbonate and a low efficiency of organic synthesis within the large dose range studied. Computer fitting of the data obtained by pulsed electron beam and fast kinetic spectrophotometry give $k(CO_2^- + HCO_3^-) \sim 2\times10^3$ $dm^3mol^{-1}s^{-1}$, $k(CO_2^- + CO_3^-) \sim 5\times10^7$ $dm^3mol^{-1}s^{-1}$, $k(NH_2 + HCO_3^-) < 10^4$ $dm^3mol^{-1}s^{-1}$ and $k(NH_2 + CO_3^-) \sim (1\text{-}2)\times10^9$ $dm^3mol^{-1}s^{-1}$.

1.11 Pulse radiolysis of aqueous solutions containing cyanide and halogens

(Z. Draganić, I.D. Draganić (Belgrade, Yugoslavia), K. Sehested, E. Bjergbakke, and J. Holcman)

The intermediates in aqueous solutions (pH ~ 8.5, N_2O saturated) of cyanide (5-50 mM) and halogenide (X): chloride (500 mM), bromide (1-5 mM) or iodide (1 mM) were examined. Preliminary experiments suggest the presence of (XCN)- transients. Their absorption spectra are similar to X_2^- with λ_{max} slightly shifted towards shorter wavelengths and with a molar extinction coefficient lower within one order of magnitude. Computer simulation of the reaction mechanism offers an insight into the intercrossing reactions which have lead to the mixed intermediates. Results obtained by irradiating aqueous solutions containing mixtures of halogenides offer supporting evidence (absorption spectra, kinetics of formation and the decay) for the existence of mixed intermediates like $(ClBr)^-$.

1.12 Radiolysis of multicomponent aqueous systems relevant to radiation chemistry of waters in nature

(I. Draganić, Z. Draganić (Belgrade, Yugoslavia), E. Bjergbakke, and K. Sehested)

The long-term effects of high levels of radioactivity on environment are of interest to various aspects of radioactive waste disposal. The finding of uranium fission chain processes in uranium ore deposits in Oklo (Gabon, Africa) shows that water in natural nuclear reactors, serving as neutron moderator and coolant, was exposed to very large doses of radiations (mixed LET), often at high temperatures and pressures. This work consists of computer simulations based on the data available on water radiolysis and natural nuclear reactors. Pulsed electron beam and fast kinetic spectrophotometry are applied in testing the onset of the chemical processes assumed in the computer modelling. The work in progress concerns a multicomponent aqueous system containing seven main constituents of sea water (> 99% of salt content). The presence of CO_2 and simple cyano compounds are also examined. These compounds are among the probable constituents of waters on the early earth and may have played a significant role in the chemical evolution processes in the early Precambrian.

1.13 Auto-oxidation of sulfite in alkaline medium

(J. Holcman and K. Sehested)

Although auto-oxidation of $SO_3^{=}$ is important from the technological as well as environmental point of view, only little is known about auto-oxidation of sulfite in the alkaline media. Preliminary experiments using the stopped-flow technique with spectrophotometric detection has shown that the presence of ozone at certain pHs does not increase the rate of auto-oxidation, whereas the addition of hydrogen peroxide or carbonate results in inhibition of the auto-oxidation process. The inhibitory action of H_2O_2 (used in acid and neutral media as an oxidant for SO_2 and HSO_3^-) and carbonate indicates that the mechanism of alkaline auto-oxidation of SO_2 ($SO_3^{=}$) is different from that in the neutral and acid region.

1.14 Reactivity of OH and O^- with aqueous methyl viologen studied by pulse radiolysis*

(S. Solar, N. Getoff (Institut für Theoretische Chemie und Strahlenchemie der Universität Wien, Austria), W. Solar (Boltzmann Institut für Strahlenchemie, Wien, Austria), J. Holcman, and K. Sehested)

The behaviour of aqueous MV^{2+} towards oxidizing radicals (OH and O^-) has been investigated in the pH range from 6 to 14 by pulse radiolysis. A semi-linear optimization method was applied for resolving the complex reaction mechanism. In the pH range from 6 to 8 the rate constant for attack by OH is $k = (2.5 \pm 0.2)\times10^8$ $dm^3mol^{-1}s^{-1}$. The resulting transient absorbs at $\lambda_{max} = 470$ nm ($\varepsilon_{470} = 1600 \pm 70$ m^2 mol^{-1}) and decays with $2k = (1.3 \pm 0.2)\times10^8$ $dm^3mol^{-1}s^{-1}$.

In strongly alkaline solutions (pH $\geq$ 13.8) the $\dot{O}^-$ radical anion reacts preferentially by hydrogen abstraction from the methyl group, $k = (1.4 \pm 0.2)\times10^9$ $dm^3mol^{-1}s^{-1}$, forming a radical which then decays by reaction with OH^- ($k = 2.8 \pm 10^6$ $dm^3mol^{-1}s^{-1}$) to produce a relatively long-lived modified radical cation with absorption maxima at 392 and 605 nm ($\varepsilon_{392} = 4300$ m^2 mol^{-1}, $\varepsilon_{605} = 1500$ m^2 mol^{-1}).

The remaining part (< 10%) of O^- attack is on the ring carbon atom, $k = (1.0 \pm 0.4)\times10^8$ $dm^3mol^{-1}s^{-1}$, resulting in an O^- adduct, which has $\lambda_{max} = 470$ nm ($\varepsilon_{470} = 2200 \pm 100$ m^2 mol^{-1}).

1.15 Pulse radiolysis of vitamins

(S. Solar, N Getoff (Institut für Theoretische Chemie und Strahlenchemie der Universität Wien, Austria), W. Solar (Ludwig Boltzman Institut für Strahlenchemie, Wien, Austria), J. Holcman, and K. Sehested)

The pulse radiolysis of nicotinic acid, NA, (the antipellagra vitamin) was performed using hydrogen at high pressure in order to study the H-atom reaction under clean conditiors in a broad range of pHs. At pH = 1 the absorption spectrum of the H adduct has maxima at 285 nm (ϵ_{285} = 4060 $dm^3mol^{-1}cm^{-1}$), 340 nm (ϵ_{340} = 2600 $dm^3mol^{-1}cm^{-1}$), 410 nm (ϵ_{410} = 160 $dm^3mol^{-1}cm^{-1}$). At higher pH only one maximum is observed at 350 nm for pH = 6.4 and at 325 nm for pH 7.8. At pH = 8-10 the transient absorption spectrum has a maximum at 315 nm. Further experiments are going on in order to resolve the acid-base properties of the H-adducts.

1.16 Computer simulations of the reactions in the Fricke dosimeter with varying Cl^- concentrations

(E. Bjergbakke)

This work is performed in collaboration with J. Swallow, Christie Hospital and Holt Radium Institute, Manchester, and B. Parsons, Kelterston College North E Wales Institute.

It has not yet been possible to obtain the necessary experimental data. A rapid-mixing instrument in connection with a pulse radiolysis set-up is needed.

1.17 Contract work for Studsvik Energiteknik AB

(H. Christensen (Studsvik Energiteknik AB, Sweden), E. Bjergbakke, and O. Lang Rasmussen (Computer Installation))

The work consists of simulation of radiation chemical reactions and mechanisms associated with radioactive waste disposal and reactor chemistry.

1.18 References

U.K. Kläning, K. Sehested and J. Holcman, Standard Gibbs energy of formation of the hydroxyl radical in aqueous solution. Rate constants for the reaction of $ClO_2^- + O_3 \rightleftarrows O_3^- + ClO_2$. J. Phys. Chem. (Issue February 1985).

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2. RADIATION PHYSICS, PHYSICAL DOSIMETRY, AND TECHNOLOGICAL APPLICATION OF RADIATION

2.1 Experimental investigation of the suitability of the track structure theory in describing the relative effectiveness of high-LET irradiation of physical radiation detectors[*1]

(J.W. Hansen)

The radiation effectiveness of heavy charged particles relative to radiations of fast electrons, x-rays, and gamma rays has been studied experimentally as well as theoretically for detectors of a thin nylon-based radiation-sensitive

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[1]This thesis is submitted with attached articles, already published or accepted for publication, to the Faculty of Science of the University of Copennagen in partial fulfilment of the requirements for the degree of lic.scient. (Ph.D).

film and for the amino acid, alanine. Experimental data have been compared with calculated data derived from a theoretical model describing the track structure of heavy charged particles.

The experimental work comprises dose-response characteristics from ^{60}Co γ-rays, 4- and 16-MV x-rays, 6-, 10-, and 20-MeV electrons, and 3-, 6-, and 16-MeV protons, 10- and 20-MeV α-particles, 21-MeV ^{7}Li ions, 42-MeV ^{14}N ions, 64-MeV ^{16}O ions, and 80-MeV ^{32}S ions.

The theoretical work presented here concerns an investigation and modification of parameters involved in the calculations, based on results obtained through the present experiments and published results from other investigators.

2.2 Theoretical and experimental radiation effectiveness of the free radical dosimeter alanine to irradiation with heavy charged particles

(J.W. Hansen and K.J. Olsen (Dept. of Radiophysics, University Hospital of Copenhagen, Herlev))

Dose-response characteristics have been measured for the crystalline amino acid L-α-alanine irradiated with ion beams of 6- and 16-MeV protons, 20-MeV α-particles, 21-MeV ^{7}Li ions, 64-MeV ^{16}O ions, and 80-MeV ^{32}S ions. The experimental radiation effectiveness, RE, with reference to low-LET radiations of ^{60}Co γ-rays, 4- and 16-MV x-rays, and 6-, 10-, and 20-MeV electrons was compared with theoretical RE-values derived from a model based on track structure theory of heavy charged particles. The ion beams covered a range in initial LET of 27-20200 MeVcm^2/g, and the experimental RE decreased with increasing LET being 1.00 for 16-MeV protons and 0.25 for the 80-MeV ^{32}S ions. The calculated RE-values were in acceptable agreement with the experimental results having a maximum deviation of 8% for the ^{7}Li and ^{32}S ions.

2.3 Investigations of the alanine dose meter

(J.W. Hansen and K.J. Olsen (Dept. of Radiophysics, University Hospital of Copenhagen, Herlev))

Dose measurements in the 160-MeV spread-peak proton beam of the Harvard cyclotron accelerator (L. Verhey, Dept. of Radiation Medicine, Massachusetts General Hospital, Boston, USA) have been evaluated. Our measurements with

alanine revealed a 7% overestimation of their calibration doses, which accordingly reduces their experimental RBE (Relative Biological Effectiveness) of 1.05-1.15 and brings the RBE more in accordance with the calculated value of 1.03.

Dr. Michael Waligorski, a visiting scientist from the Institute of Nuclear Physics, Krakow, Poland, has compared our computer program REINT for calculation of relative radiation effectiveness (RE) for physico-chemical detectors with the programs (ROSELIB) developed at the University of Lincoln, USA (R. Katz). The ROSELIB programs include subroutines which are used in the CHIT.MRC (Lincoln) program for calculation of RE for neutron irradiations. The program CHIT.MRC has been specially designed for handling fast neutron spectra of the cyclotron at the Medical Research Council (MRC), Hammersmith Hospital, London, but could be used in an interpretation of fast neutron irradiations of our alanine dose meters performed in Krakow. The fast neutron spectra of the Krakow and the MRC cyclotrons are almost identical. Results from the REINT program have been checked with experimental data from high-LET irradiations of alanine performed at Risø, covering a range in particle energy and charge which is very similar to that of secondary particles following fast neutron irradiation of tissue, which is well approximated by alanine. If results from the ROSELIB programs could fit data obtained from the REINT program, the CHIT.MRC program could yield an interpretation of experimental data readily. The ROSELIB subroutines, however, did not meet results with REINT very accurately. This is why it was decided to incorporate subroutines from the Risø program REINT. This work was not finished within the limited time of Dr. Waligorsky's stay, but will be continued during his one year stay at Lincoln, USA.

To facilitate more easily the mechanical manufacturing of the alanine pills on the pill-pressing machine in the Health Physics Department and to lower the ESR background signal, new additives to the alanine dosimeters have been investigated. The binding material polyvidon seems to fulfill these demands and will as well increase the mechanical strength of the pill.

The alanine dose meters have in several cases been used for calibration of irradiation facilities outside Risø. An EF-contract proposal has been submitted concerning development of alanine as a personal accidental dose meter, and as well concerning theoretical predictions of dose-response for alanine exposed to high-LET radiations.

2.4 Film dosimetry

(A. Miller and W. Batsberg Pedersen (Chemistry Dept.))

Production of radiochromic dye film dosimeters containing a dye, which is purified at the Chemistry Department, has been delayed because of purity problems with the raw material. Contacts are maintained with a company that will make a prototype dosimeter when the dye is ready. Under a contract with CERN it is proposed to develop a dosimeter based on the film dosimeter, which may be used visually to detect radiation around the new CERN accelerator (LEP).

2.5 Other dosimeters

(A. Miller and L. Xie)

The properties of other dosimeters (lyoluminescence of glutamine, various PVC films) are investigated. The glutamine dosimeter was tested at different humidities both at cobalt and electron irradiation, and commercial PVC-foils were tested at electron irradiation using different post-irradiation treatments. This work is carried out with the assistance of a visiting scientist from Beijing, China.

2.6 Dosimetry training course

(A. Miller)

In the spring of 1984 a one-week training course in dosimetry for gamma facility operators and users was arranged. There were 15 participants from 5 countries and lecturers from this department, Health Physics Department, Statens Seruminstitut, National Bureau of Standards, USA, Institute of Isotopes, Hungary, and National Physical Laboratory, UK.

2.7 Calorimetry

(A. Miller and A. Kovacs (Institute of Isotopes, Budapest, Hungary))

Graphite and water calorimeters are used for dose calibration of the 10-MeV electron accelerator. The water calorimeters have been used for several years mainly for measurement of dose in the range for radiation sterilization, and

the graphite calorimeter offers the possibility of measuring lower doses. The graphite calorimeter may easily be electrically calibrated, and we have found good agreement between electrical calibration and dose readings based on material properties only. We have found small differences between dose readings with the two types of calorimeters. These differences are investigated by intercomparisons with National Bureau of Standards, Washington, D.C. and National Physical Laboratory, London. This work is supported by IAEA research contract no. 3583, and some of the work was carried out with assistance from an IAEA fellow.

2.8 Dose standardization

(A. Miller)

Efforts are continued through the IAEA to establish a "Dose Assurance Service". This service will be offered to operators of gamma facilities during 1985, and steps have been taken to initiate a similar service for electron beam facilities.

In standardized dosimetry proper application of cavity theory is important, but in practical dosimetry, however, these corrections often amount to only a few percent. A paper on this matter was presented at an IAEA dosimetry conference.

We are participating in an ICRU-working group with the purpose of writing a report on "Dosimetry for Radiation Processing". The report will constitute a set of guidelines for practical high-dose processing dosimetry.

2.9 Commercial irradiations

(A. Miller and W. Batsberg Pedersen (Chemistry Dept.))

Commercial irradiations were expanded since the installment in early 1984 of the new conveyor at the linear electron accelerator. Product boxes of maximum standard size 80×60×30 cm^3 can be handled, but other sizes may also be accommodated. Contract irradiations are carried out for several customers, and we serve as a back-up for Danish commercial irradiation facilities.

2.10 Calibration and consultive assistance

(A. Miller and J.W. Hansen)

Calibration of dosimeters were carried out for several customers using the department's cobalt facilities. Dosimeters were in some cases issued for irradiation in a customer's facility, and subsequent read-out here. Alanine (ESR read-out) and radiochromic dye films (optical read-out) were used for these purposes, and the films were also used for dose distribution measurements. Consultive assistance was offered often in connection with the dose measurement.

2.11 References

J.W. Hansen and K.J. Olsen, Theoretical and Experimental Radiation Effectiveness of the Free Radical Dosimeter Alanine to Irradiation with Heavy Charged Particles. Submitted: Radiat. Res.

W.L. McLaughlin, A. Miller, R.M. Uribe, S. Kronenberg, and C. Siebentritt, Energy Dependence of Radiochromic Response to X and Gamma Rays. Int. Symp. on High-Dose Dosimetry, IAEA, Vienna, 8-12 Oct. 1984, IAEA-SM-272/9, to be published.

W.L. McLaughlin, J.C. Humphreys, and A. Miller, The Measurement of High Doses Near Metal and Ceramic Interfaces. Int. Symp. on High-Dose Dosimetry, IAEA, Vienna, 8-12 Oct. 1984, IAEA-SM-272/10, to be published.

W.L. McLaughlin, A. Miller, F. Abdel-Rahim, and T. Preisinger, Plastic Film Materials for Dosimetry of Very Large Absorbed Doses. 5th Int. Meet. on Radiation Processing, San Diego, CA., 22-26 Oct. 1984, to be published in Rad. Phys. Chem.

A. Miller, Calculation of Energy Dependence of Some Commonly Used Dosimeters. Int. Symp. on High-Dosimetry, IAEA, Vienna, 8-12 Oct. 1984, IAEA-SM-272/27, to be published.

A. Miller and A. Kovacs, Calorimetry at Industrial Electron Accelerators. 8th Conf. on Application of Accelerators in Research and Industry, Denton, Texas, 12-24 Nov. 1984, to be published.

K.J. Olsen and J.W. Hansen, Experimental Data from Irradiation of Physical Detectors Disclose Weaknesses in Basic Assumptions of the δ-ray Theory of Track Structure, to be published in Radiat. Prot. Dosim.

F. Abdel Rahim, A. Miller, and W.L. McLaughlin, Responses of Radiation Monitoring Labels to Gamma Rays and Electrons. 5th Int. Meet. on Radiation Processing, San Diego, CA., 22-26 Oct. 1984, to be published in Rad. Phys. Chem.

3. RADIATION BACTERIOLOGY RESEARCH

Bacteriological research concerns the developing and testing of radiation sterilization processes, as well as advice and assistance on specific projects to prospective users of radiation sterilization. Research interests are concentrated on the mechanisms of radiation resistance.

3.1 W-reactivation in Acinetobacter calcoaceticus

(D. Berenstein)

A virulent phage of A. calcoaceticus, HP2, has been shown to be a subject for W-reactivation in its host strain, 11959, and a subject of W-reactivation, restriction and modification in another strain, A5. Neither the UV dose that induced maximum W-reactivation in A5, nor any other UV doses had any influence on the restriction and modification activities of this strain. This stands in contrast to other investigated bacterial systems, e.g. Bacillus, where a coordinate induction of W-reactivation and a DNA modification system has been described.

3.2 Plasmid content of Acinetobacter strains

(D. Berenstein)

More than 50 Acinetobacter strains isolated from urinary tract infections in Danish patients were obtained from Rigshospitalet (University Hospital), Copenhagen. The strains were assayed for phenotypic traits that normally are conferred by plasmids and for presence of plasmids by gel electrophoresis.

The majority of the strains were resistant to penicillins, trimetoprim and nitrofurantoin and were sensitive to aminoglycosides, tetracyclines, chloramphenicol and rifampicin. Almost all strains showed the presence of many plasmid bands (up to 10), but is seemed that strains resistant to a greater number of antibiotics revealed a smaller number of plasmids. No transmissible plasmids were detected and no correlations could be made between possession of a specific plasmid and any phenotypic marker. The failure to detect any transmissible antibiotic or metal resistance plasmid prompted the suggestion that resist-ance mechanisms in Acinetobacter may involve chromosomally located transposons. This possibility is planned to be investigated in collaboration with Dr. Vivian during a sabbatical stay at Bristol Polytechnic.

3.3 Genome size and complexity in Acinetobacter calcoaceticus

(D. Berenstein)

A. calcoaceticus contains both radiation-sensitive and radiation-resistant strains. A project has been started to investigate if there is any correlation between radiation resistance and genome size, number of chromosome equivalents per single cell and DNA composition (G + C%). Preliminary results show no difference in the DNA content per cell between radiation-resistant and radiation-sensitive strains.

3.4 Production and supply of microbiological standard preparations and biological indicators

(D. Berenstein)

The laboratory produced, supplied and assayed standard preparations of the spore former Bacillus cerius, strain C 1/1, as well as of the vegetative A. calcoaceticus, strain OA4. Tests of the microbiological efficiency of a Danish radiation facility were performed.

Sterility tests have been performed for radioactive samples supplied by Risø's Isotope Laboratory to the medical industry. Bacterial count estimates have also been performed for private companies on several occasions.

1984 was the last year when such service could be given by the Bacteriology Laboratory of our department, as the whole bacteriology group is being transferred to the Agricultural Department in 1985.

4. OPERATION AND MAINTENANCE OF IRRADIATION FACILITIES

4.1 HRC electron linear accelerator

(J. Fenger and B. Lynggård)

The accelerator has been in operation for a normal number of hours. About 65% of the time the facility was used for experimental irradiation, mostly in connection with the pulse radiolysis equipment. 30% of the time was used for service irradiation on the beam conveyor. Maintenance of the facility covered about 5% of the time. The following maintenance works were carried out:

Injector system. A set of light links for the 250-kV injector was replaced after only half a year in operation. Already in 1983 there were problems with x-ray degradation of the light links. The supplier was faced with the problem, but no solution was given and we intended to use another type of light link. A plastic light link was chosen as it is much less sensitive to x-rays. Besides the problems with x-rays the light link must withstand the aggressive transformer oil and the high-voltage potential (250 kV over a length of 0.5 m). The light link transmitter and receiver electronics were modified to match to the new plastic light links. The new light links have been in operation half a year, and no problems in regard to x-ray exposure have been observed.

Microwave system. The high-power klystron has been in operation for more than 10,000 hours and its efficiency has gradually decreased. To obtain the rated microwave power for the accelerator the electrical power from the transmitter has gradually been increased, but now the limit for further increase has been reached and consequently the accelerator beam power will decrease until the klystron is replaced.

After two years in operation the RF driver output was decreased by 50% and was insufficient to saturate the klystron. By increasing the high voltage the output power was back to normal. Half a year later a flash-over occurred in the triode cavity damaging the triodes and 142.7 MHz transistor amplifier. The units were repaired in the department.

Beam-scanning system. A new scanner system for the electron beam is under construction and will be installed in 1985.

4.2 Febetron, field-emission accelerator

The field-emission accelerator was used for pulse radiolysis of gases and for Raman spectroscopy. Five defective modules caused a malfunction. Three of the defective modules were repaired, and two were replaced by new spare modules.

4.3 ICT, low-energy accelerator

The low-energy accelerator was used for dosimetry and polymerization experiments. The operation was trouble-free.

4.4 10,000 Ci ^{60}Co-facility

The 10,000 Ci ^{60}Co-facility was used for radiation research and for customer services. It further serves as a reference source for microbiological efficiency testing according to the IAEA's recommendations for the radiation sterilization of medical products. The operation was trouble-free.

4.5 5,000 Ci ^{60}Co-facility

The 5,000 Ci ^{60}Co-cell, presently located in the Control Department of the Danish Serum Institute, Copenhagen, was used for bacteriological research. The old mechanical timers controlling the irradiation time were replaced by a digital electronic unit.

4.6 3,000 Ci ^{60}Co-facility

The 3,000 Ci ^{60}Co-cell was used for research in radiation chemistry, radiation bacteriology, and customer services. The operation was trouble-free.

4.7 Lambda Physik Excimer laser

The laser was use during 2 periods for fast ESR at Institute of Chemistry, Aarhus University, during 2 periods for Raman spectroscopy in connection with the Febetron by the Chemistry Department, and once for flash photolysis by the Accelerator Department. The operation and maintenance of the laser has taken more time than expected mainly due to transportation and reinstallation at the three different locations. The thyratron was replaced 2 times on warranty. The last thyratron is from another manufacturer and is rated for higher power.

4.8 Flash photolysis set-up

The installation of the flash photolysis set-up was continued. There have been problems with noise signals from the laser; the problems will be solved by galvanically isolating the laser from the detector computer system.

4.9 Xenon flash lamp

The testing of a 5 Joule xenon flash lamp for use as a UV light source in the pulse radiolysis set-up was begun.

4.10 PDP-11/10 computer

An old PDP-11/10 computer with disk and magnetic tape units (earlier used in the Metallurgy Department) was installed to be used for the flash-photolysis set-up. The operation of the computer has been very cumbersome due to malfunctioning of the disk unit. The problems were not solved by the end of the year.

5. EDUCATIONAL ACTIVITIES AND PUBLICATIONS

5.1 Lectures

E.H. Appelmann (Argonne National Laboratory, USA), Reactive Fluorine Compounds in Aqueous Solution. Risø, 29 May.

D. Cabelli (Brookhaven National Laboratory, USA), HO_2/O_2^- Reactions with Manganese Complexes. Risø, 14 June.

J.W. Hansen, "Diskussion af Sporstrukturmodeller til Beskrivelse af Fysiske og Biologiske Systemers Respons på Høj-LET Stråling (Discussion of Track Structure Models Describing the Reponse to High-LET Radiations of Physical and Biological Systems). H.C. Ørsted Institute, June 28.

A. Miller, "Fødevarebestråling" (Food Irradiation). Risø, 15 June.

A. Miller and A. Kovacs, Calorimetry at Industrial Electron Accelerators. 8th Conf. on Application of Accelerators in Research and Industry, Denton, Texas, November 12-14.

A. Miller, Calculation of Energy Dependence of Some Commonly Used Dosimeters. Int. Symp. on High-Dose Dosimetry, IAEA, Vienna, October 8-12.

Dissertation, lic.scient (Ph.D),

J.W. Hansen, "Experimental Investigation of the Suitability of the Track Structure Theory in Describing the Relative Effectiveness of High-LET Irradiation of Physical Radiation Detectors". University of Copenhagen, June 28.

Lectures at Dosimetry Training Course, Risø, May 7-11.

"Interaction of Radiation with Matter".
J.W. Hansen, Accelerator Dept.
"Fundamentals of Dosimetry".
W.L. McLaughlin, National Bureau of Standards, USA.

"Calibration of Dosimeters".

J. Barret, National Physical Laboratory, England.

"Sources of Error in Dosimetry".

Arne Miller, Accelerator Dept.

"Plant Commissioning".

W.L. McLaughlin, National Bureau of Standards, USA.

"Radiation Sterilization".

E.A. Christensen, Statens Seruminstitut (National Serum Institute).

Dosimeters, Theory and Practice

Fricke	K. Sehested, Accelerator Dept.
Film systems	W.L. McLaugnlin, National Bureau of Standards, USA.
Dichromate	J. Barret, National Physical Laboratory, England.
ESR, alanine	J.W. Hansen, Accelerator Dept.
Ethanol chlorobenzene	A. Kovacs, Institute of Isotopes, Hungary.
Lyoluminescence	A. Miller, Accelerator Dept.
Thermoluminescence	Poul Christensen, Health Physics Dept.
Optichromic system	W.L. McLaughlin, National Bureau of Standards, USA.
Ceric-cerous	J. Holcman, Accelerator Dept.
Perspex	J. Barrett, National Physical Laboratory, England.
Dose distribution	A. Miller, Accelerator Dept.

5.2 Publications

Accelerator Department - Annual Progress Report, 1 January - 31 December 1983. Risø-M-2423.

E. Bjergbakke, K. Sehested, O. Lang Rasmussen and H. Christensen, Input Files for Computer Simulation of Water Radiolysis. Risø-M-2430.

H. Christensen and E. Bjergbakke, Radiolysis of Concrete. Studsvik Report NW-83/434.

H. Christensen and E. Bjergbakke, Radiolysis of Iodine in a BWR Additional Calculations. Studsvik Technical Note NW-84/682.

H. Christensen and E. Bjergbakke, Radiolysis of Concrete. Svensk Kärnbränsleförsörjning AB/Avdeling KBS, Stockholm, Sweden, KBS 84-02.

H. Christensen and E. Bjergbakke, Radiolys Av Hydrazin I Vattelösning. Studsvik Report NW-84/704.

H. Christensen and E. Bjergbakke, Effect of β-Radiolysis of Ground Water. Studsvik Report NW-84/763.

H. Christensen and E. Bjergbakke, Radiolysis of Concrete. J. OF INDUST. IRRADIATION TECH., 2(3&4), 321-344.

H. Christensen and K. Sehested, Pulse Radiolysis at High Temperatures and Pressures. Progress report for 830701/840630. Studsvik Technical Note NW-84/784.

E.J. Hart, W.G. Brown and E. Bjergbakke, The Mechanism of O^3P Atom Formation in γ-Ray Irradiated and UV Photolyzed Aqueous Solutions. Radiat. Phys. Chem. 23, No. 1-2, 181-186.

J.W. Hansen, Experimental Investigation of the Suitability of the Track Structure Theory in Describing the Relative Effectiveness of High-LET Irradiation of Physical Radiation Detectors. Risø-R-507.

J.W. Hansen and K.J. Olsen, Experimental and Calculated Response of a Radiochromic Dye Film Dosimeter to High-LET Radiations. Radiat. Res. 97, 1-15.

J.W. Hansen and M. Wille, Problems Associated with the Use of the Radiochromic Dye Film as a Radiation Dose Meter. Radiat. Phys. Chem. 23, No. 4, 455-462.

J. Holcman, K. Sehested, E. Bjergbakke and E.J. Hart, The O_3^- Radical Reaction in Neutral and Alkaline Solutions. Proc. Third Int. Conf. on Oxygen Radicals in Chemistry and Biology, Neuherberg, Federal Republic of Germany, July 10-15, 1983, p. 43-48 (eds. W. Bors, M. Saran and D. Tait), Walter de Gruyter, Berlin, New York.

U.K. Kläning, K. Sehested and Th. Wolff, Ozone Formation in Laser Flash Photolysis of Oxoacids and Oxoanions of Chlorine and Bromine. J. Chem. Soc., Faraday Trans. I, 80, 2969-2979.

O. Lang Rasmussen and E. Bjergbakke, CHEMSIMUL - A Program for Numerical *Simulation of Chemical Reaction Systems*. Risø-R-395.

A. Miller, Dose Calibrations of Industrial Electron Accelerators. J. OF INDUST. IRRADIATION TECH., 2(3&4), 367-383.

A. Miller and W.L. McLaughlin, Measurement of Absorbed Dose and Dose Distribution. Radiation for Plastics and Rubber II, Canterbury, UK, March 28-30, 1984. Proceedings published by the Plastics and Rubber Industry, London.

A. Miller, Dosimetry for Electron Beam Application. Research in Radiation Processing Dosimetry. Final report of the co-ordinated research program on High-Dose Standardization and Intercomparison for Industrial Radiation Processing, organized by IAEA, and Proc. of the final research co-ordination meeting held in Munich 8-11 Nov. 1983. IAEA-TECDOC-321, p 159, IAEA, Vienna.

K.J. Olsen and J.W. Hansen, Experimental and Calculated Effectiveness of a Radiochromic Dye Film to Stopping 21 MeV ^{7}Li- and 64 MeV ^{16}O Ions. Nucl. Instr. & Meth. B5, 497-504.

K. Sehested, J. Holcman, E. Bjergbakke and E.J. Hart, Formation of Ozone in the Reaction of OH with O_3^- and the Decay of the Ozonide Ion Radical at pH 10-13. J. Phys. Chem. 88, 269.

K. Sehested, J. Holcman, E. Bjergbakke and E.J. Hart, A Pulse Radiolytic Study of the Reaction OH + O_3 in Aqueous Medium. J. Phys. Chem. 88, 4144.

S. Solar, W. Solar, N. Getoff, J. Holcman, and K. Sehested, Hydrogen-atom Attack on Methyl Viologen in Aqueous Solution Studied by Pulse Radiolysis. J. Chem. Soc., Faraday Trans. I, 80, 2929-2934.

5.3 Irradiation and dosimeter calibration

Irradiation, dosimeter calibrations, etc. have been performed for:
Alupa, Belgium
Asea, Stockholm
Brown, Boveri & Cie A/S, Germany
Centralsygehuset, Nykøbing F

W. Cook Europe ApS, Bjæverskov

Damvig, Tåstrup

De Danske Sukkerfabrikker

Danmarks tekniske Højskole

Dannmarks farmaceutiske Højskole

L. Dæhnfeldt A/S, Odense

Euro Hospital Production AB, Sweden

A/S Ferrosan, Søborg

Fibiger-Laboratoriet

Gambro Lundia AB, Sweden

A/S L. Goof, Hørsholm

Johnson & Johnson, Sweden

J.C. Hansen, Harlev J

Institutt for Energiteknikk, Norway

I.R.E., Mediris, Belgium

Københavns Amts Sygehus, Glostrup

H.V. Lassen, København

LBH Industriteknik ApS

LUMINO-Fabriken A/S, Esbjerg

Løvens kemiske Fabrik

Marselisborg Hospital, Århus

Medox-Surgimed, Ølstykke

Mialens, Tåstrup

Microtronic ApS, Roskilde

Mölnlycke A/S, Espergærde

A/S Nordiske Kabel- og Trådfabriker, Glostrup

Novo Industri A/S, Bagsværd

A/S Nunc, Roskilde

Odense By & Amtssygehus

Pharmacia AB, Sweden

Radiflex ApS, Hedehusene

Raychem A/S, Glostrup

Rehau Plastiks AG + CO, Germany

Rigshospitalet, København

Sankt Hans Hospital, Roskilde

Scandidakt, Humlebæk

Strålskyddstjänst AB, Sweden

Statens Seruminstitut, København

Århus Kommunehospital Århus.

5.4 Visiting scientists

H. Christensen, Studsvik Energiteknik AB, Nyköping, Sweden.
I. and Z. Draganić, Beograd, Yugoslavia.
L. Falvi, Institute of Isotopes, Budapest, Hungary.
N. Getoff, Institut für Strahlenchemie, Vienna, Austria.
P. Hargittai, Institute of Isotopes, Budapest, Hungary.
E.J. Hart, Port Angeles, WA., USA.
U. Kläning, Kemisk Institute, Aarhus Universitet, Aarhus.
A Kovacs, Institute of Isotopes, Budapest, Hungary.
A. Hadjinia Lailabadi, Atomic Energy Organization of Iran, Teheran, Iran.
W.L. McLaughlin, National Bureau of Standards, Gaithersburg, MD, USA.
V. Stenger, Institute of Isotopes, Budapest, Hungary.
S. and W. Solar, Institut für Strahlenchemie, Vienna, Austria.
R. Tanaka, JAERI, Takasaki, Gunma-Ken, Japan.
M.P.R. Waligorski, Institute of Nuclear Physics, Krakow, Poland.
L. Xie, Institute of Low Energy Nuclear Physics, Beijing Normal University, Beijing, China.

6. IRRADIATION FACILITIES AT THE ACCELERATOR DEPARTMENT

Electron Accelerators

1. Linear Electron Accelerator, Haimson Research Corp. Model HRC-712

Specifications:

Electron energy	10 MeV
Average electron current	1 mA
Peak electron current at 10 MeV	1100 mA
Pulse length	0.01 - 4 μs
Pulse repetition rates	single pulses and 12.5, 25, 37.5, 50, 100, 150, and 200 pps.

Accelerator room beam facilities:

1. A bent beam with scan width of 60 cm in connection with a conveyor system provides a capacity of irradiating e.g. 400 kg at 35 kGy per hour.
2. Two horizontal beam ports, full average beam power, for electron and X-ray irradiation.
3. One horizontal beam port, reduced average beam power (12.5 pps) in connection with an energy analyzing spectrometer.

Target room beam facilities:

1. Three horizontal beam ports, reduced average beam power (12.5 pps).

2. Field-Emission Electron Accelerator, Febetron Model 705B

Specifications:

Electron energy ..... 1.5 - 2.0 MeV
Peak electron current ..... 4000 MeV
Pulse length ..... 50 ns

3. Low-Energy Electron Accelerator, High Voltage Eng. Corp. Model EPS 400-IND

Specifications:

Electron energy ..... 400 keV
Electron current ..... 50 mA
Scan width ..... 120 cm
The accelerator is provided with conveyor to permit pilot-plant irradiation.

4. Excimer Laser, Lambda Physik Model EMG102 E[1]

Specifications:

Active medium	F_2	ArF	KrCl	KrF	XeCl	N_2	XeF	
Wavelength	157	193	222	249	308	337	351	nm
Pulse Energy (min)	10	200	30	250	150	7	100	mJ
Pulse width (FWHM)		14	9	16	10	6	14	ns
Single pulse and repetition rates up to	80	80	100	100	100	100	50	Hz

^{60}Co-Facilities

10,000 Ci ^{60}Co-facility (built at Risø 1957)

Designed for very homogeneous irradiation of samples with a maximum of 180, 100, or 60 mm. The corresponding maximum dose rates (5,600 Ci (2.1×10^{14} Bq), 1 January 1985) are 3.4×10^{5}, 9.6×10^{5}, and 2.2×10^{6} rd$\times$h^{-1} (1, 2.7, 6 Gy$\times$s^{-1}), respectively.

5,000 Ci ^{60}Co-facility (built at Risø 1971)

Designed for laboratory use and fitted with a 123 mm$\varnothing\times$150 mm irradiation chamber. The dose rate in the center of the chamber (3,400 Ci (1.3×10^{14} Bq), 1 January 1985) is 2.9×10^{5} rd$\times$h^{-1} (0.81 Gy$\times$s^{-1}). The cell is located at the Control Department, Statens Seruminstitut, Copenhagen.

3,000 Ci ^{60}Co-cell (built at Risø 1968)

Designed for laboratory use and fitted with a 120 mm$\varnothing\times$200 mm irradiation chamber. The dose rate in the center of the chamber (2,100 Ci (7.7×10^{13} Bq), 1 January 1985) is 2.1×10^{5} rd$\times$h^{-1} (0.58 Gy$\times$s^{-1}).

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[1]An appropriation by the Danish Natural Science Research Council, on shares with Aarhus University.

7. STAFF OF THE ACCELERATOR DEPARTMENT

Head : Knud Sehested

Office Staff: Ebba Haugaard and Ruth Madsen

Scientific Staff

Dvora Berenstein

Erling Bjergbakke

Jørgen Fenger

Johnny W. Hansen

Jerzy Holcman

Bent Lynggård

Arne Miller

Jørgen Poulsen (left January 31)

Liqing Xie (visiting scientist from June 25)

Technical Staff

Margit Elm Andersen

Karen Boysen (left February 29)

Hanne Corfitzen

Ina Hansen (transferred to the Agricultural Dept. September 1)

Jørgen Erik Hansen

Stig Sandberg Jensen (from November 19)

Torben Johansen

Erik Engholm Larsen

Fritz Larsen

Inge Merete Larsen

Gert Hagen Olsen

Kresten Pejtersen

Mads Wille

Consultants

Dr. E.A. Christensen, Chief Physician, Control Department, Statens Seruminstitut (National Serum Institute), Copenhagen.

Dr. E.J. Hart, Port Angeles, WA., USA.

W.L. McLaughlin, Physicist, Center for Radiation Research, National Bureau of Standards, Washington, D.C., USA.

Risø National Laboratory **Risø - M - 2494**

Risø - M - 2494

Title and author(s)

Accelerator Department - Annual Progress Report
for the period 1 January - 31 December 1984.

Acceleratorafdelingens årsrapport
1 januar - 31 december 1984.

Date March 1985

Department or group

ACCELERATOR

Group's own registration number(s)

36 pages + tables + illustrations

Abstract

A description is given of work in the fields of radiation chemistry and reaction kinetics, physical dosimetry, radiation physics and technological application of radiation, radiation bacteriology research and irradiation technology, as well as of the operation of various irradiation facilities.

Copies to

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